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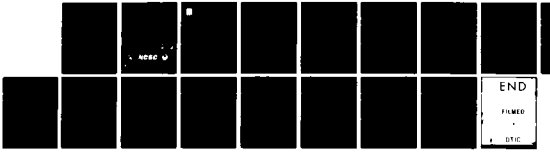

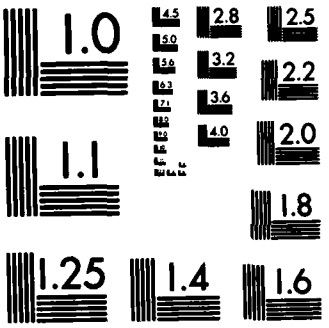

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DECEMBER 1982

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THE EFFECTS OF PULSATILE FLOW ON CARBON DIOXIDE ABSORPTION BY HIGH PERFORMANCE SODASORB

A. PURER
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December 1982

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The effects of pulsatile flow on carbon dioxide absorption by high performance Sodasorb was investigated using previously developed methods. This investigation covers both a saturated and dry carrier gas with average linear velocities from about 2 to 12 centimetres per second at a pulse rate of 20 to 110 cycles per minute. A small breathing machine was used to generate the pulsatile flow. Pulsatile flow was found to be more efficient than constant flow with a dry carrier gas. A more complex relationship was observed for a saturated carrier

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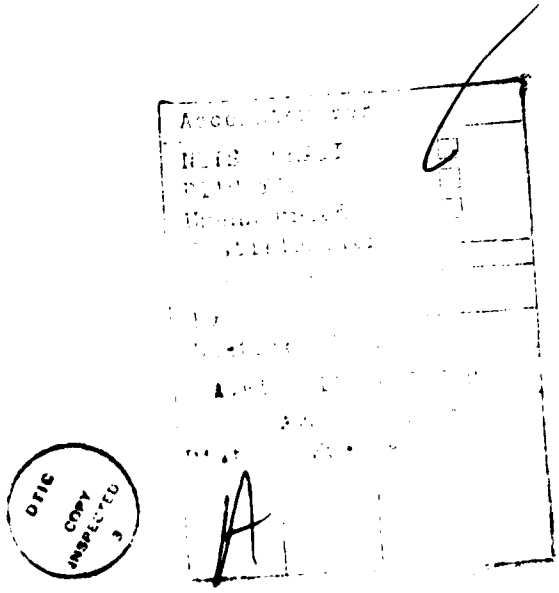
20. ABSTRACT (continued):

gas; however, the trend was for pulsatile flow to be less efficient at high linear velocities. At low linear velocities, the efficiencies of the pulsatile flow approached that of constant flow.



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INTRODUCTION

The project covered in this report is part of a continuing applied research project to evaluate the various factors that affect the efficiency of carbon dioxide (CO_2) absorption using hydrated calcium hydroxide. Such information is needed to design high efficiency semi-closed and closed circuit breathing systems for diving applications.

The report presents the results of a series of tests which evaluated the effects of pulsatile flow typical in human propelled breathing systems on CO_2 absorption using previously developed methods.[1] [2] [3] Both a water-saturated and dry carrier gas composed of 1 percent CO_2 in helium (He) with pulse rates from 20 to 110 cycles per minute with a corresponding carrier gas linear velocities of 2 to 12 centimetres per second were investigated.

High performance Sodasorb, 4 to 8 mesh, manufactured by W. R. Grace and Company, was used in this study as in previous investigations.[1] [2] [3] The reported specification of chemical composition for this material is 14 to 19 percent water (H_20), 75 to 80 percent calcium hydroxide [$Ca(OH)_2$] and 4 to 6 percent activators which consist mostly of sodium hydroxide (NaOH). The material also has an ethyl violet pH indicator.[4] As the caustic is consumed, the resulting pH change causes the indicator to change from colorless to purple. This color change often represents only surface pH of the particles and thus may not be a reliable indicator of absorbent use. This color can change back to colorless with time because of unconsumed caustic present in the interior of the particle. Therefore, used absorbent may be colorless and still be exhausted for all practical purposes.

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[1]Naval Coastal Systems Center Technical Memorandum NCSC TM 327-81, "Carbon Dioxide Absorption Characteristics of High Performance Sodasorb at 1 Atmosphere Pressure," by A. Purer, G. A. Deason, M. L. Nuckols, and J. F. Wattenbarger, October 1981.

[2]Naval Coastal Systems Center Technical Memorandum NCSC TM 349-82, "The Effects of Pressure and Particle Size on Carbon Dioxide Absorption Characteristics of High Performance Sodasorb," by A. Purer, G. A. Deason, B. H. Hammonds, and M. L. Nuckols, June 1982.

[3]Naval Coastal Systems Center Technical Memorandum, "The Effects of Various Moisture Content Sodasorb on Carbon Dioxide Absorption Characteristics," by A. Purer, G. A. Deason, and M. L. Nuckols (in publication).

[4]Grace, W. R., The Sodasorb Manual of Carbon Dioxide Abosrption, Library of Congress Catalog, Card No. 62-14923, pp. 33-34, copyright 1962.

APPARATUS AND PROCEDURE

The basic laboratory apparatus used in this study (Figure 1) is similar to that previously reported[1 2 3] with the addition of a scaled down version of a breathing machine, a modified scuba regulator, oscilloscope, and a low pressure transducer with its associated strip chart recorder. The scuba regulator had two functions. First, it stepped down the CO_2-He inlet gas pressure from 60 to 70 psig to a slightly positive pressure suitable for intake into the breathing machine. Secondly, it acted as a one-way valve to isolate the absorption cell from the breathing machine on its gas intake stroke.

In order to obtain as close as possible isothermal conditions across the absorption cell, helium, with its high thermal conductivity, was used as the diluent gas. The internal diameter of the absorption cell was 0.978 centimetre with a length of 12.50 centimetres; the absorbent occupied about 6.5 centimetres of the cell length. The small cell dimensions limited the maximum distance that a gas molecule could be from the constant temperature maintained cell walls. Each end of the absorption cell was equipped with a CPV O-ring type connector. These connectors allowed easy access to the cell while ensuring a gas-tight seal during a run. The flat ends of this type of connector facilitated volume calculations. A 4-gram (±0.01) absorbent charge was normally used.

If a dry gas stream was desired, the 1 percent CO_2 in He mix would go directly into the absorption cell. For a saturated carrier gas, the gas mixture would first pass through a bubble tower containing water. In either case, the gas mixture would pass through temperature equilibrating coils before entering the absorption cell.

The breathing machine was of the reciprocating piston design with an adjustable crankshaft for varying the stroke and thus the piston displacement. Piston displacement could be varied from 0 to over 1500 cubic centimetres; for this series of runs, the displacement was set equal to the true dead volume of the charged cell. A variable speed drive motor operating through a gear box was used to turn the crankshaft at speeds ranging from about 16 to 120 cycles per minute. Feed gas for the breathing machine was obtained through a modified scuba regulator. This regulator was also used as a one-way valve for the displaced gas from the breathing machine. Gas from the breathing machine-regulator assembly passed through a flow restrictor. The differential pressure transducer across the flow restrictor was used to record gas flow rate, breathing profile, and cycles per minute. This unit was calibrated by passing a constant flow of gas through the system with the absorption cell charged with absorbent as in a normal run. Flow rate was obtained by dividing the accumulated gas volume from the wet test meter by total time of run. These calibrations allow calculations of the linear velocity across the individual particles during any portion of a breathing cycle as displayed in Figure 2.

The constant temperature bath used in these tests could maintain a temperature of ±0.1°C of its set point.

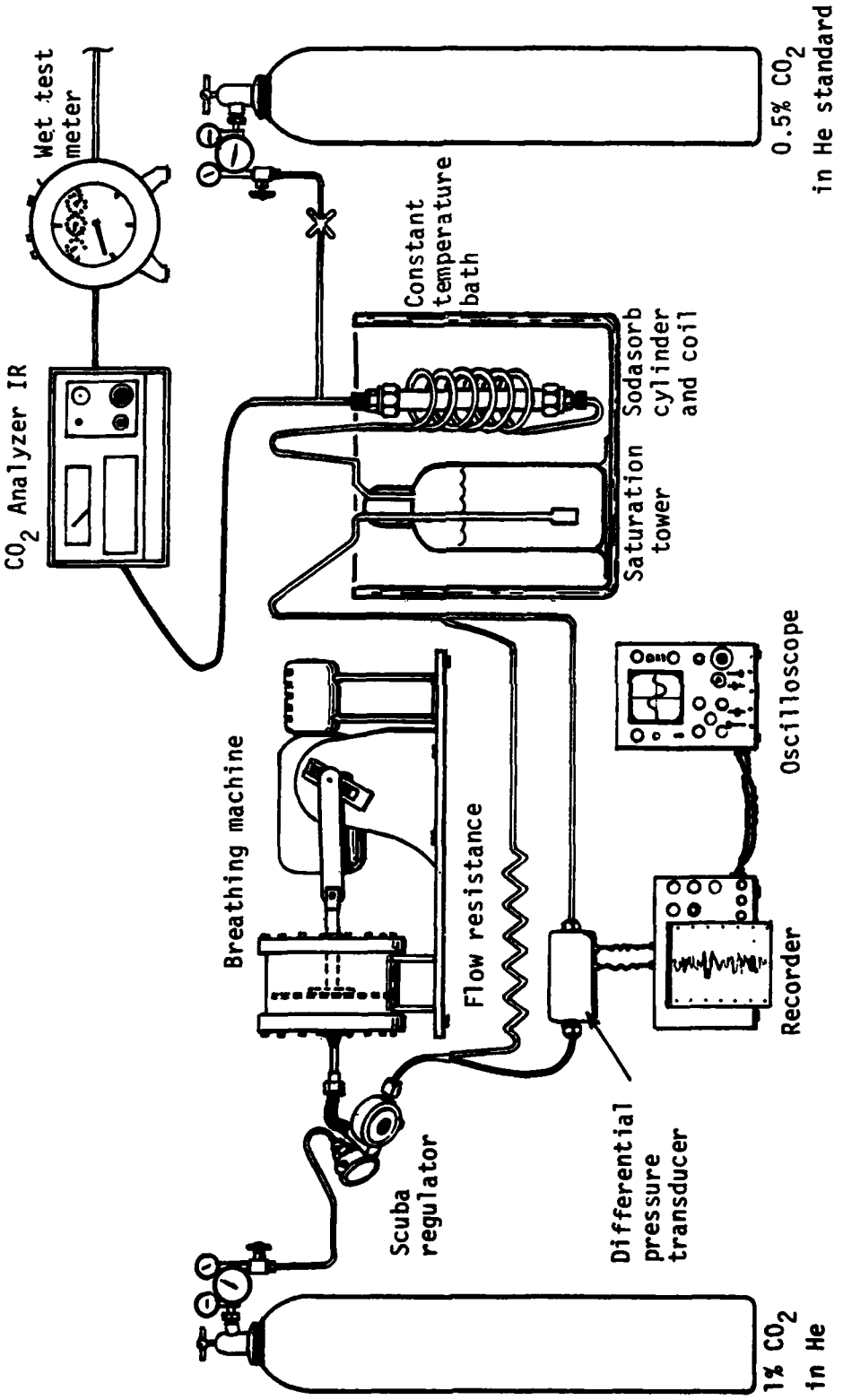

FIGURE 1. CO_2 ABSORBENT TEST APPARATUS FOR PULSATILE FLOW

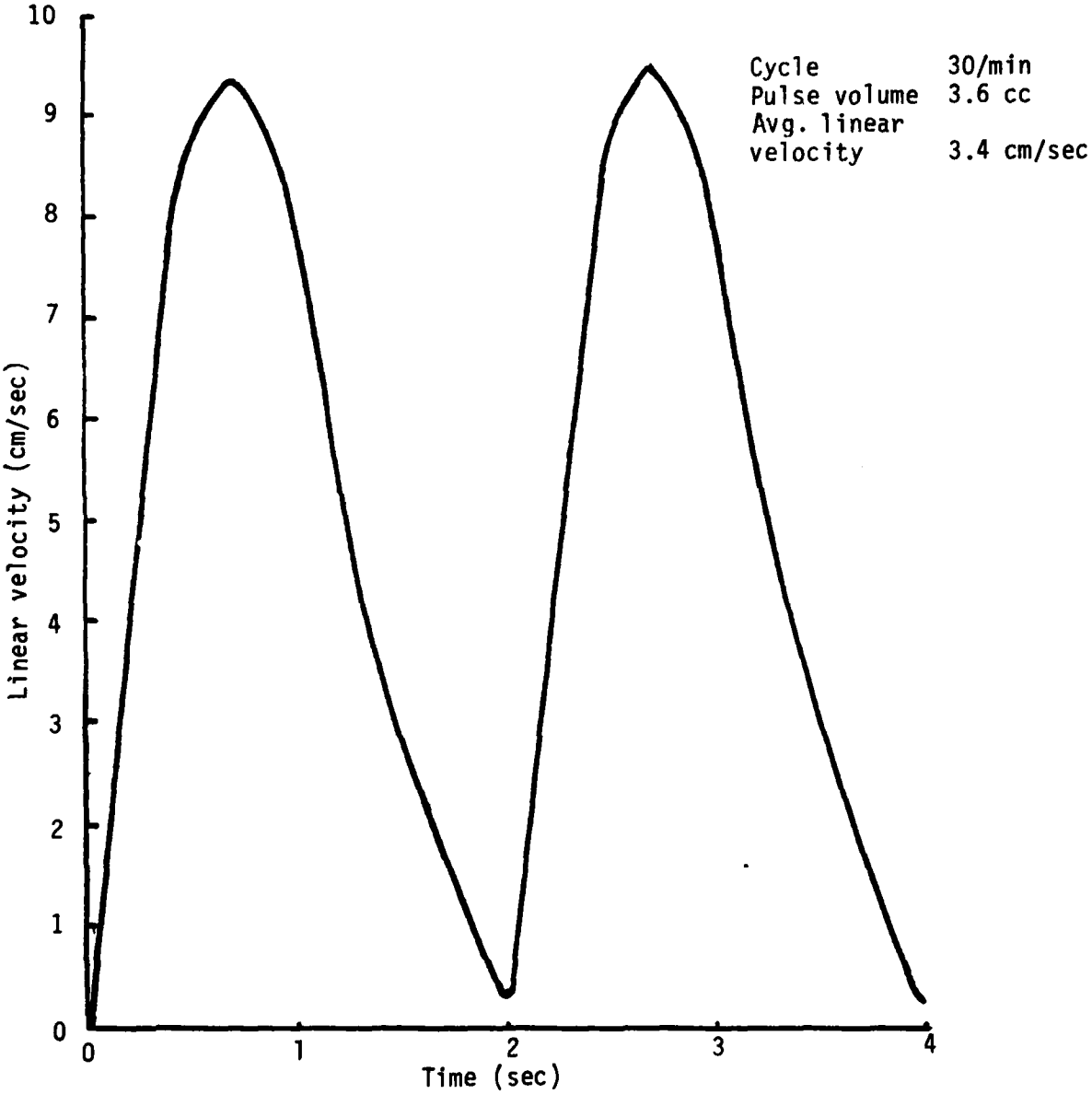

FIGURE 2. RELATIONSHIP BETWEEN LINEAR VELOCITY AND PULSATILE GAS FLOW

Carbon dioxide content of the effluent gas stream was obtained with a Beckman Model 865 CO_2 Infrared Analyzer. Each run was terminated when the effluent CO_2 level reached 0.5 percent (3.8 Torr partial pressure). Total flow was recorded with a Precision Instrument wet test meter.

CALCULATIONS

The weight of absorbent used in each run was divided by the absolute density to obtain the volume of the solid absorbent. The absolute density of the absorbent was obtained by filling a container of known empty volume with a weighed amount of absorbent. The inter particle volume was then obtained by expanding a known volume of helium at a known pressure into the absorbent-filled canister.[1,5] The absorbent volume, subtracted from the canister volume occupied by the Sodasorb, represented the dead volume of the cell and the effective volume available for gas flow.

Dividing this volume by flow yields the mean time individual gas molecules would spend in the cell (residence time). Dividing effective cell length by the mean time a gas molecule spends in the cell yields a time-averaged linear velocity. This measure of gas flow can now be used as a means of direct comparison with continuous flow studies.

Finally, absorption efficiency is defined as the number of litres of 1 percent CO_2 in He passed through the test cell before exit gas reaches 0.5 percent per gram of absorbent. The efficiencies obtained apply only to cells with parallel walls.

TEST RESULTS

DRY CARRIER GAS

Experimental runs were made at 70°F (21°C) with a dry carrier gas at linear velocities from 2 to 12 centimetres per second with corresponding pulse rate of 20 to 110 cycles per minute. The displacement volume for each pulse was adjusted to 3.7 cubic centimetres compared to the cell dead volume of 3.5 cubic centimetres in an attempt to completely displace all the gas that was in the cell from the previous cycle.

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[1]ibid.

[5]Purer, A., Hoffman, C. A., and Smith, D. R., "Chromatographic Determinations of Column Dead Volume and Absolute Density of Absorbent at Cryogenic Temperature," J. Gas Chromatography, Vol. 6, March 1968.

The results of this study are shown in Figure 3. The vertical axis represents the litres of 1 percent CO_2 in He that entered the cell before the exit gas reaches the 0.5 percent CO_2 level. The horizontal axis represents the time-averaged linear velocity of a molecule passing through the cell. Because the volume of gas that passed through the cell with each pulse was constant, average linear velocity could only be changed by varying the cycles per minute. Therefore, a second horizontal axis displays the cycles or pulse per minute. Since the gas was pulsed through the cell, the linear velocity would vary over a wide range during each pulse. This is shown in Figure 2 which shows the relationship of linear velocity of a gas molecule during one cycle (at a cycle rate of 30 cycles per minute) with an average linear velocity of about 3.4 centimetres per second. The linear velocity during this cycle varied from near 0 to 9.5 centimetres per second. This high linear velocity could conceivably allow some CO_2 molecules to pass through the cell without being absorbed, particularly at a higher pulse rate. This effect would be even more likely if the total gas volume moved per cycle were greater than the dead volume of the cell.

Since the efficiency of the pulsatile flow was higher than that of the steady state flow for CO_2 absorption for the dry carrier gas (Figure 3), it was suspected that a larger amount of CO_2 passed through (by passing the absorption particles) the cell at the start of a run for pulsatile flow than for continuous flow. Thus, the absorbent would be consumed initially at a higher rate in the initial stage of the continuous flow testing. The breakthrough level of 0.5 percent CO_2 in the exit gas (by definition in Reference 1) would be reached sooner by the continuous flow. The total amount of CO_2 absorbed could be higher for the continuous flow; however, its efficiency would appear to be lower. This was confirmed by comparing the CO_2 concentration of the exit gas at the same time-flow (volume) intervals for pulsatile and continuous flow for runs with the same average linear velocity (Figure 4). This figure shows a higher concentration of CO_2 in the exit gas for the first 19.5 litres of flow for the pulse system. During this first 19.5 litres, less absorbent was chemically reacted for the pulsatile flow than the continuous flow. This unused absorbent was still available for later use. Thus, the continuous flow run, already having used a larger portion of its absorbent, approached the 0.5 percent CO_2 breakthrough level at a higher rate than the pulsatile flow system. The pulsatile flow did not reduce the CO_2 to as low a level as the continuous flow. Thus, its use of absorbent was spread out over a longer time period.

SATURATED CARRIER GAS

Experimental runs were made at 70°F (21°C) with a saturated 100 percent relative humidity carrier gas at linear velocities from 2 to 12 centimetres per second and a pulse rate of 20 to 110 cycles per minute. Each pulse had a displacement volume of about 3.7 cubic centimetres which assured a complete purge of the 3.5-cubic centimetre cell dead volume.

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[1]ibid.

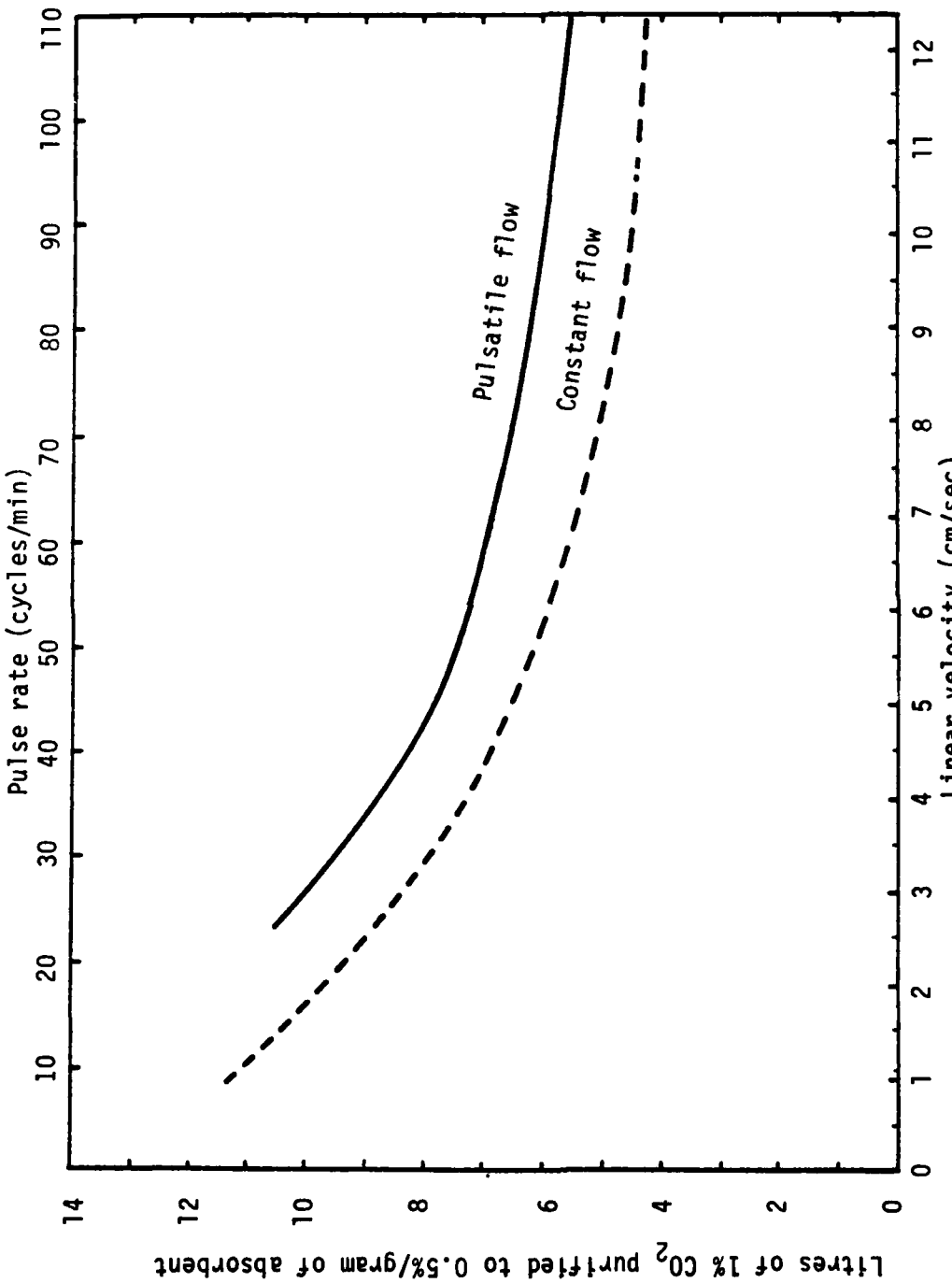


FIGURE 3. HIGH PERFORMANCE SODASORB EFFICIENCIES WITH A DRY CARRIER GAS

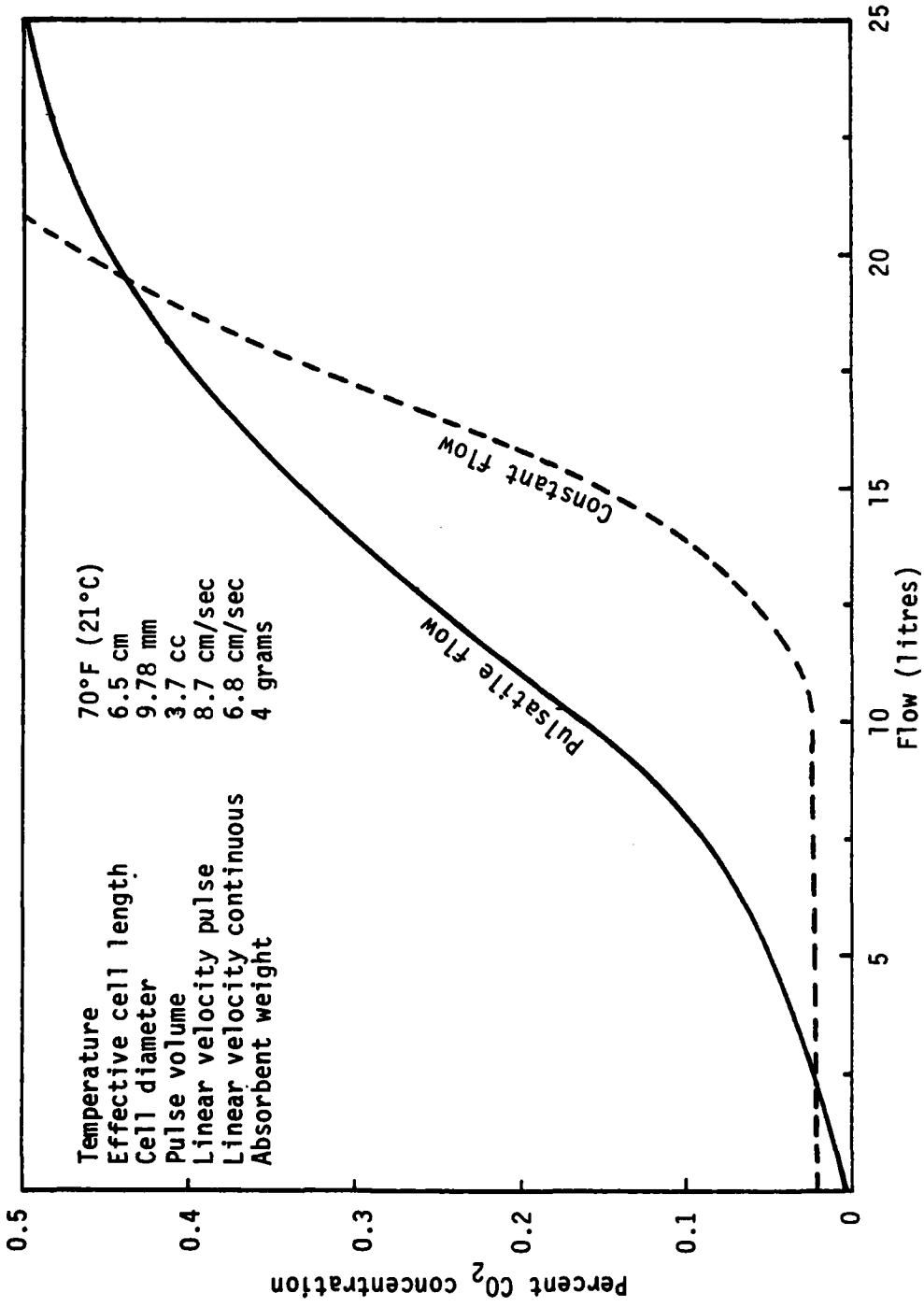


FIGURE 4. CO_2 CONCENTRATION OF EFFLUENT FLOW FOR PULSE AND CONTINUOUS FLOW WITH A DRY CARRIER GAS

The results of these studies are shown in Figure 5. This figure shows that pulsatile flow was less efficient than continuous flow for a water-saturated carrier gas. The difference in efficiency of the pulsatile and constant flows becomes smaller at low linear velocities. This can be observed by the apparent converging of these two curves at low linear velocity in Figure 5. Figure 5 shows constant flow more efficient than pulsatile flow for the water-saturated system; this is a reversal from the effects observed in the dry system of Figure 3. The increase in efficiencies for a dry carrier gas and the trend of decreased efficiencies for a saturated carrier gas for pulsatile flows reduced the effects of water vapor (Figure 6) as compared to constant flow.[1] This reversal in efficiencies is not understood. In an attempt to obtain an insight into this observed reversal in efficiencies, the CO_2 concentration of the exit gas at the same time-flow (volume) intervals for pulsatile and continuous flow for runs with the same average linear velocity were compared (Figure 7). However, this comparison was to no avail. It revealed that less absorbent was chemically reacted in the pulsatile flow. However, for some unknown reason this unused absorbent was not available for later use under the 0.5 percent breakthrough level. Other possible factors that could reduce the CO_2 interaction with the absorbent are decreased diffusion, increased linear velocities, and inaccessibility of the absorbent. The slowest rates of diffusion of a gas molecule would probably be into and across the water layer. Increasing the thickness of this layer could possibly increase the time requirement beyond that available between pulses. Also, if the water film filled the pores, water volume and pore volume the same, the total surface area for CO_2 interaction with the absorbent would be greatly reduced. This would have an adverse effect on efficiency of both steady state and pulsatile flow. However, the high linear velocities encountered at the peaks of pulsatile flow may tend to magnify this effect.

CONCLUSION

The effects of pulsatile flow on CO_2 absorption characteristics of high-performance Sodasorb for water-saturated and dry gas streams at 1 atmosphere pressure were investigated. Pulsatile flow was found to be more efficient than constant flow with a dry gas stream and less efficient for a water-saturated gas stream. Thus the contribution of water vapor was not as noticeable for the pulsatile flow as it was for the continuous flow.

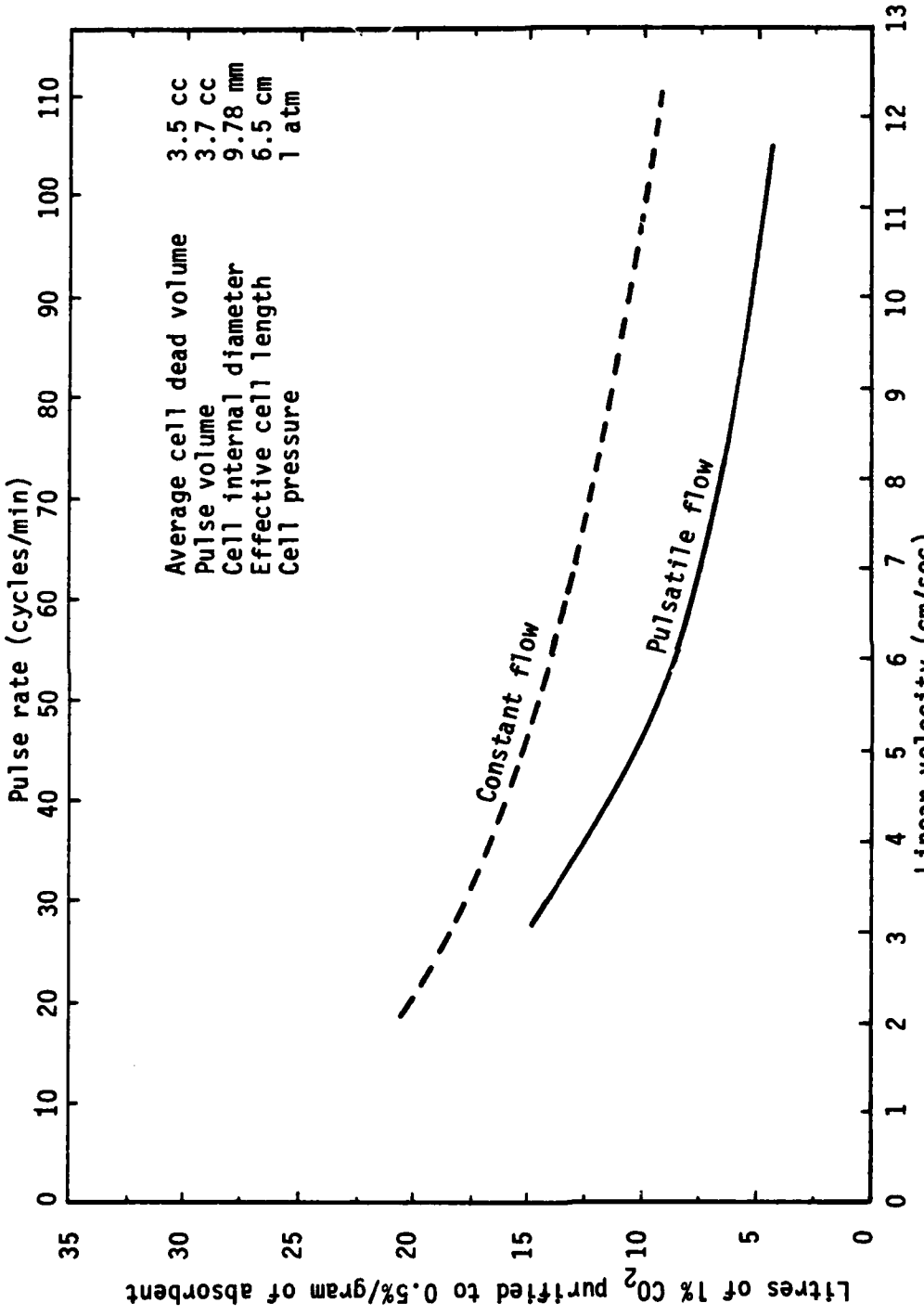


FIGURE 5. HIGH PERFORMANCE SODASORB EFFICIENCIES WITH A SATURATED CARRIER GAS

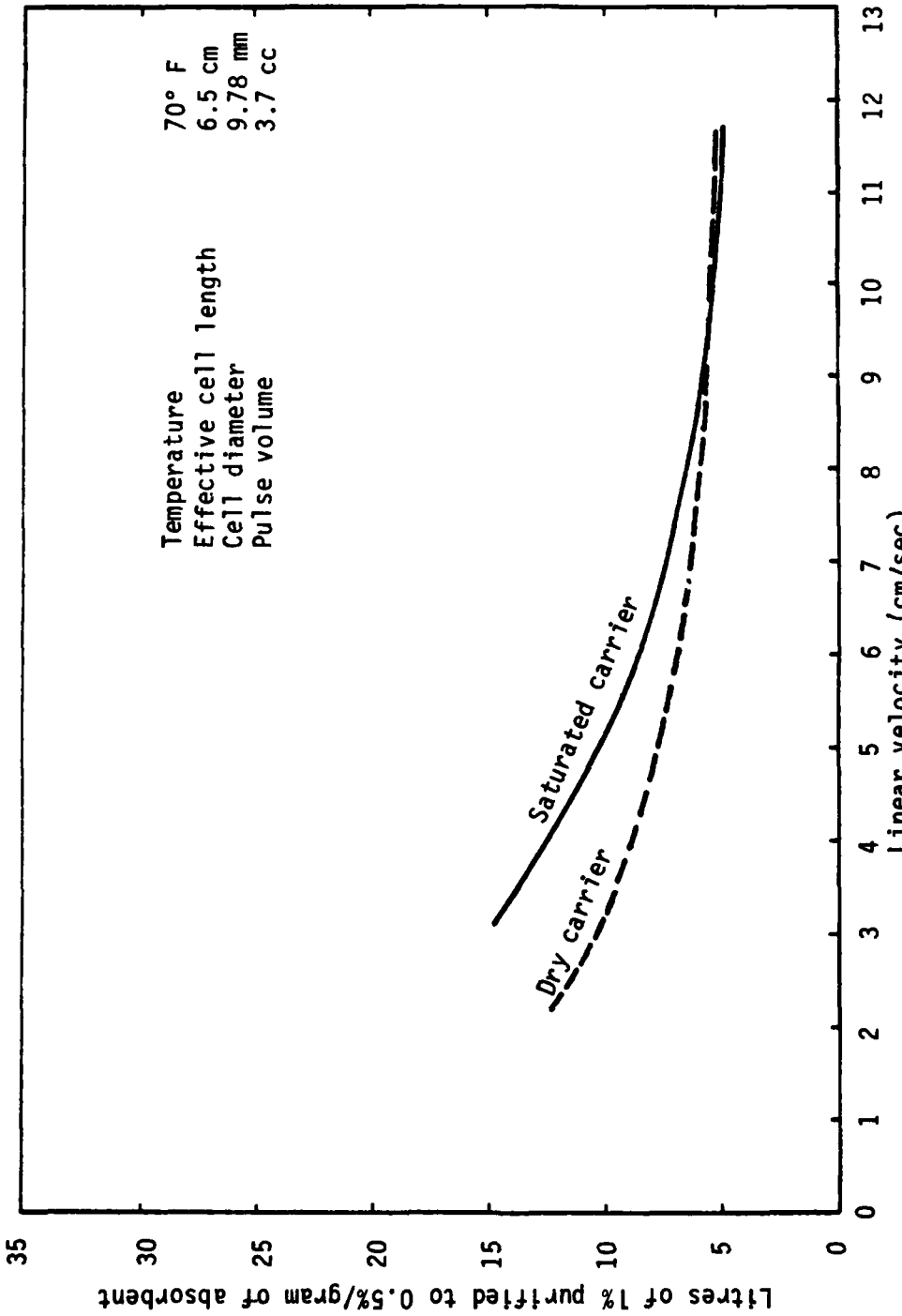


FIGURE 6. THE EFFECTS OF DRY AND SATURATED CARRIER GAS ON H. P. SODASORB EFFICIENCIES FOR PULSATILE FLOW

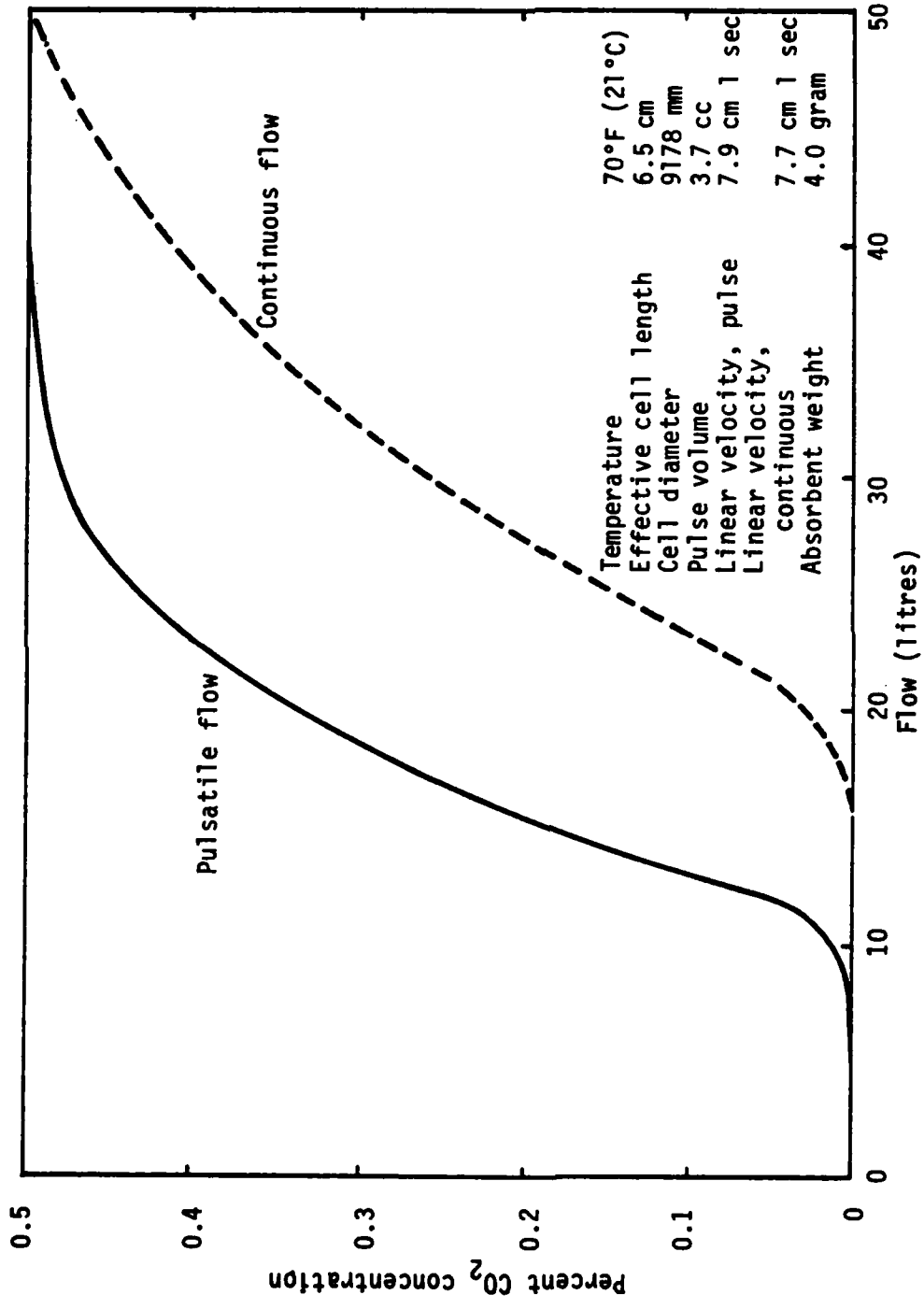
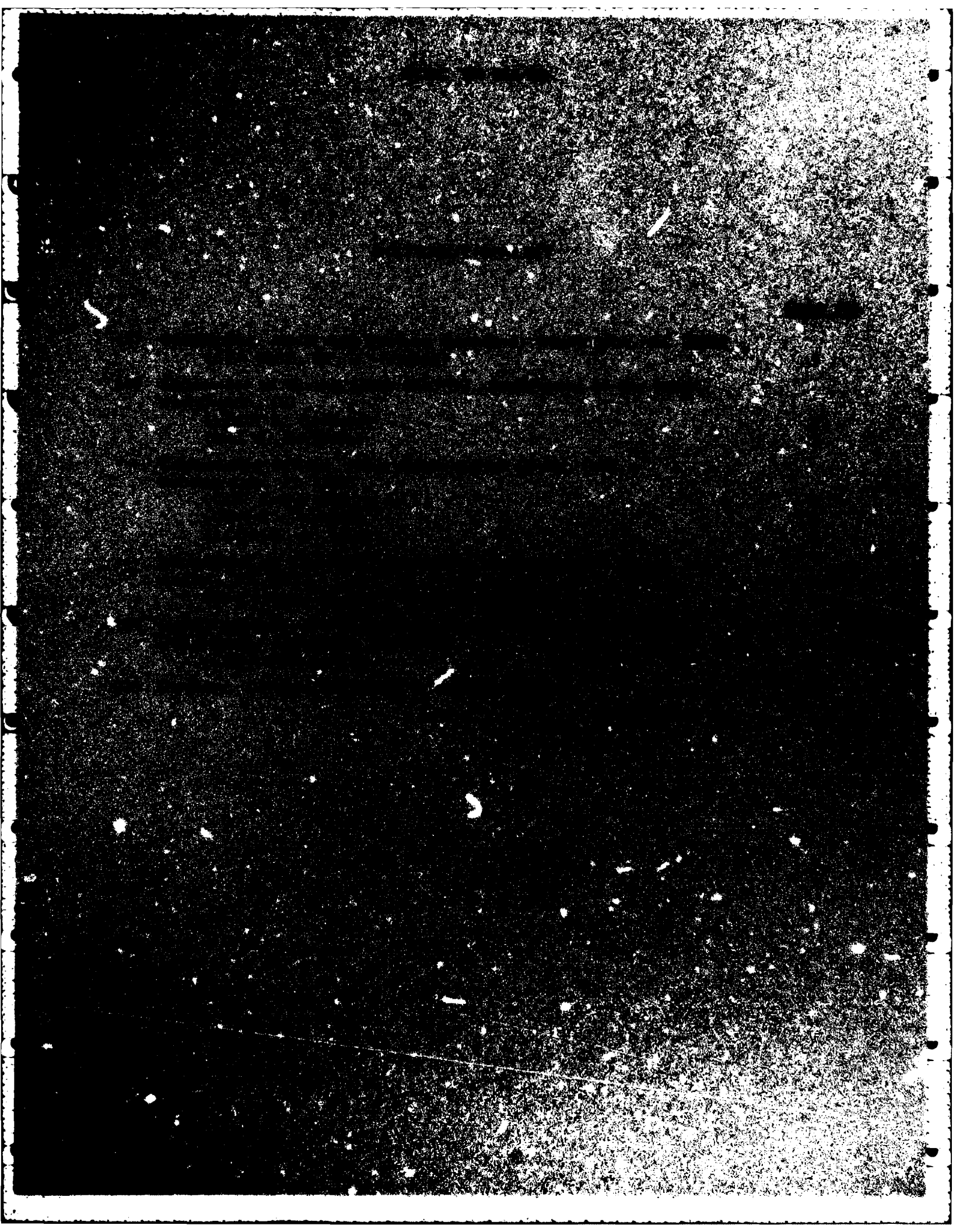


FIGURE 7. CO_2 CONCENTRATION OF EFFLUENT FLOW FOR PULSE AND CONTINUOUS FLOW WITH A SATURATED CARRIER GAS



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